Lawrence Armstrong Deposition Exhibits 2 & 3

March 31, 2008

Preliminary Report Prepared by Lawrence E. Armstrong, Ph.D., FACSM

For Attorney Paul De Marco
Waite, Schneider, Bayless & Chesley, L.P.A.
1513 Fourth & Vine Tower
One West Forth Street
Cincinnati OH 45202

Re: Kelci Stringer v. National Football League et al.
U.S. District Court Southern District of Ohio Case No. 03-665

Dear Mr. De Marco:

I received your request to review documents regarding the July 31, 2001 heat stroke and subsequent death of Korey Stringer, NFL football player. My comments below address the roles of primary factors in the generation of internal heat production, heat storage in the body, and dissipation of heat from the body. My analysis is based on my academic training (i.e., in physiology, nutrition, exercise metabolism and biology), professional experiences as a thermal/exercise physiologist, participation as an expert witness in other deaths by exertional heatstroke, and research that I have conducted involving the influence of a football uniform on exercise-induced hyperthermia.

In preparation of my opinion, I have reviewed deposition transcripts, one videotape, relevant position stands of professional organizations, and published scientific articles.

Based on the information provided to me, Korey Stringer experienced exertional heatstroke on July 31, 2001 during an early-season training session with the Minnesota Vikings professional football team, during the initial days of summer training.

Heat Balance in the Human Body: General Considerations

Humans constantly produce heat, via metabolism of food nutrients or stored body fat and via exercise. Humans also must remove heat from the body, or body temperature rises to a level that damages internal organs. A diagnosis of heatstroke is made when body temperature exceeds 39 – 40°C (about 103 – 104°F), and when altered mental status (i.e., confusion, unconsciousness, coma) or sensations of nausea or vomiting appear. Exertional heatstroke is a sinister medical emergency, but much can be done to prevent it, and proper treatment (i.e., via ice water immersion) certainly reduces the risk of death from exertional heatstroke to nearly zero.

Various environmental factors play a role in heat storage within the human body, including: air temperature, air humidity, air velocity, solar radiant energy, and clothing or uniform insulation. Numerous individual characteristics play a role in heat storage in humans, including: metabolic rate (i.e., especially as influenced by exercise), muscle mass, body fat content, hydration status, cardiorespiratory physical fitness, heat acclimatization status, acute illness (i.e., presence of fever), and age.

Published Research Regarding the Physiological Effects of Wearing a Uniform or Clothing Insulation on Heat Storage in Humans

If a football game is played in a hot environment, dry heat loss via radiation and convection is reduced because the thermal gradient from skin to air decreases; high humidity further decreases skin

DEFENDANT'S EXHIBIT

cooling via evaporation of sweat because the air is nearly saturated with water vapor. The role of a uniform in this potentially harmful confluence of circumstances was first acknowledged in the pioneering studies of Fox, Matthews and colleagues (Fox EL, Mathews DK, Kaufman WS, Bowers RW. Effects of football equipment on thermal balance and energy cost during exercise. Research Quarterly 37: 332-339, 1966; Mathews DK, Fox EL, Tanzi D. Physiological responses during exercise and recovery in a football uniform. Journal of Applied Physiology 26: 611-615, 1969) 50 years ago. They observed that the American football uniform acted as a barrier to heat loss, and increased metabolic heat production due to its weight.

Since 1966, two published scientific studies have illuminated our understanding. The first study (Kulka TJ, Kenney WL. Heat balance limits in football uniforms. Physician and Sports Medicine 30:29-39, 2002) observed eight college-aged men who were not competitive football players, while they walked on a motor-driven treadmill at 35% of their maximal aerobic power (VO_{2max}). Using numerous combinations of air temperature and relative humidity (range, 29 – 39°C and 15 – 65%rh), the investigators sought to identify the points at which esophageal temperature indicated uncompensable heat stress (i.e., the body's thermoregulatory systems cannot compensate adequately). Test subjects wore either a practice uniform or a full game uniform; the latter ensemble included the practice uniform plus game pants (not shorts) with thigh, knee, and hip pads. Although these subjects did not wear shorts, the results of a control trial from a previous study were provided. Using this approach, the investigators identified zones of uncompensable heat stress for each uniform, above which body temperature rose without plateauing. In all environments studied, the uniform increased the physiological stress experienced by test subjects. The American College of Sports Medicine utilized these data to develop preliminary guidelines for uniform use in hot environments (Armstrong LE, Casa DJ, Millard-Stafford M, Moran DS, Pyne SW, Roberts WO. Exertional heat illness during training and competition. American College of Sports Medicine Position Stand. Medicine & Science in Sports & Exercise 39: 556-572, 2007).

The second relevant laboratory study (Hitchcock KM, Millard-Stafford ML, Phillips JM, Snow TK. Metabolic and thermoregulatory responses to a simulated American football practice in the heat. Journal of Strength and Conditioning Research 21: 710-717, 2007) evaluated the energy cost of a simulated American football practice in a 28°C, 55%rh environment. Five offensive linemen served as test subjects and wore either shorts (the control condition), shorts + helmet, shorts + helmet + shoulder pads, or a full game uniform; the third and fourth ensembles differed only by four small thigh and hip pads. The simulated practice session lasted 60 minutes; it incorporated 49.5 minutes of intermittent exercise (e.g., simulating various football skills) and ended with 2 minutes of continuous running (8 mph, 0% grade). The conclusions included these points: (a) the core body temperature was higher ($P < 0.05$) while wearing helmet + shoulder pads versus the uniform containing only the helmet, at time-points after 30 minutes; and (b) the addition of shoulder pads increased core temperature and energy cost, especially during recovery between active drills in unacclimatized linemen.

<u>Other Sources That Warn About the Thermoregulatory and Cardiovascular Burden of a Football Uniform in Hot Environments</u>

The following few sources represent numerous publications and web pages that warn about the risk of serious hyperthermia or exertional heat illness, resulting from wearing a full American football uniform:

- National Center for Catastrophic Sport Injury Research, Chapel Hill, NC; this Center reported that 264 deaths occurred due to exertional heat stroke from 1994 to 2005 (combined high school, college and professional teams)
- American College of Sports Medicine: Position Stand titled, "Youth Football: Heat Stress and Injury Risk"; this Position Stand notes that 21 young football players died of exertional heat stroke in the United States from 1995 – 2001; it also concludes that the insulation of a uniform leads to a greater physiological strain for a given environmental condition

- Journal of the American Medical Association 233: 513 - 515, 1975; this article advises that wearing a football uniform, especially the helmet, increases the risk of fatal hyperthermia
- Journal of the American Medical Association 194: 180-184, 1965. this article recommends that lightweight uniforms be worn during practice and early-season games.

Research Investigation Conducted at the University of Connecticut

As noted above, exercise physiology and sports medicine authorities have realized the potentially harmful effects of wearing a football uniform in a hot environment since 1966. For example, the American football helmet, protective pads, socks, jersey and pants reduce heat dissipation to the air. Exercise-induced metabolic heat production raises core body temperature without a plateau and readily induces uncompensable heat stress. The combined gain of heat (metabolically) and the diminished loss of heat (due to a uniform and a hot environment) can result in life-threatening heat storage in the organs of the body.

Because only four previously published studies have measured the direct thermal and cardiovascular strain that results from wearing a football uniform, a research investigation was conducted at the University of Connecticut, Human Performance Laboratory during the months of October through December, 2007. The purpose of this study was to describe differences of thermal and physiological responses during exercise in a hot environment, while wearing one of three uniforms per experiment: **Control** - shorts, socks, sneakers; or **Partial** - (shorts, socks, sneakers, jersey, pants, gloves, pads on legs, hips, arms, shoulders and chest) minus the helmet and shoulder pads; or **Full Uniform** - (shorts, socks, sneakers, jersey, pants, gloves, pads on legs, hips, arms and chest) including Riddell shoulder pads and a Riddell helmet; the vintage of the helmet and shoulder pads was about 2001. Ten male test subjects participated in three experiments each, while wearing one uniform per session. All subjects completed the Control, Partial, and Full Uniform experiments. Air temperature, air relative humidity, and subject hydration state (i.e., body weight, urine specific gravity) were controlled from day-to-day.

The exercise-rest protocol consisted of 10 minutes of repetitive box lifting (RBL), 10 minutes of seated rest, followed by up to 60 minutes of treadmill walking. RBL consisted of lifting a 20.4 kg (45 lb) metal box with handles for 10 minutes. After lifting the box, subjects walked 2.4 m to place it on a platform that is 1.32 m high. An investigator slid the box down a ramp to the starting position after each lift. Each subject used his legs when lifting the box from the floor, as demonstrated and practiced during the familiarization visit. He placed his feet close to the box, bent his knees, and held up his head. Each subject received a minute-by-minute countdown and feedback regarding pace; the rate of box lifting was identical in all experiments. Based on a study conducted in our laboratory during Winter 2006, subjects lifted the box 100 times per 10 minute period; this was a challenging but achievable effort for these for these test subjects who all were former football players.

The personal characteristics of the ten male test subjects appear below (mean ± SD). Each had played team football for at least three years.

Subject	Age years	Body weight kg (lb)	Height cm (in)	Body fat % [a]	Fat Mass kg (lb) [a]	Lean Body Mass kg (lb) [a]
Mean	23.8	117.41 (258.84)	183.9 (72.4)	30.1	33.5 (73.9)	76.7 (169.1)
± Std. Dev.	4.3	12.59 (27.75)	6.3 (2.5)	5.5	8.4 (18.5)	3.2 (7.1)

[a], as determined by DEXA (dual x-ray absorptiometry) scan, considered to be today's gold standard body composition technique

Our conclusions were as follows:

1. Skin temperature was greater in Full Uniform versus Control (at the neck and forearm) and Full Uniform versus Partial (at the neck).
2. Humidity (%rh) was high in all uniforms (Control, Partial, Full) and statistically similar.
3. Sweat rates were similar in Partial and Full Uniform; both of these were greater than Control clothing.
4. The number of test subjects who reached a rectal temperature of 39.0°C (102.2°F) was recorded as follows: Control – 4, Partial – 6, Full Uniform – 6. This level of hyperthermia is considered to be the lower body temperature threshold at which exertional heatstroke begins (ACSM 2007).
5. From Min 20 to Min 40 of treadmill exercise, Partial (no helmet and no shoulder pads) caused an increase of rectal temperature (i.e., due to heat storage in the deep tissues of the body) that was 2.0 times greater than Control; Full Uniform caused an increase of rectal temperature that was 2.7 times greater than Control; the helmet and shoulder pads caused 43% of this increase in rectal temperature.
6. During the entire treadmill exercise bout, Partial Uniform (no helmet or shoulder pads) caused rectal temperature to rise 1.4 times faster than Control, whereas the Full Uniform caused rectal temperature to rise 1.9 times faster than Control. During the entire treadmill exercise bout, the helmet and shoulder pads accounted for 56% of the total rectal temperature rise of the Full Uniform.
7. The statistical regression analysis of the lines for the Control, Partial and Full uniforms allowed a statistical prediction of the physiological values that would have been reached, during a 2-hour exercise bout.
   - Rectal temperature after 2 hours of treadmill walking is predicted to be:
     - Full Uniform – 42.0°C (107.6°F)
     - Partial (no H or SP) – 40.8°C (105.4°F)
     - Control – 39.1°C (102.2°F)
   - Heart rate after 2 hours of treadmill walking was predicted to be:
     - Full Uniform – 218 beats/min
     - Partial (no H or SP) – 190 beats/min
     - Control – 163 beats/min

   The age-predicted maximal heart rate in this group of men (220 – age) was 196, meaning that Partial Uniform and Full Uniform would have brought these men to their maximal heart rate (i.e., exhaustion) during a 2-hour practice session.

Appendix A contains the entire final report submitted on 10 January 2008.

In addition to the above findings (which are my opinions, based on scientific research), I present the following:

It is my opinion to a reasonable degree of scientific certainty that the helmet and shoulder pads worn by Korey Stringer added considerable weight and insulated his body. Thus, I conclude that the helmet and shoulder pads were substantial contributing factors to Mr. Stringer's hyperthermia and ultimate death. Removing uniform parts (i.e., helmet) during rest periods (or scheduling practices that involve no helmet, shoulder pads, or other insulative uniform parts) is one important preventive measure that could save lives, but this was not allowed during the practice session on July 30, 2001 or July 31, 2001.

<u>History as an Expert Consultant Since 2004</u>

- Provided deposition Summer, 2005 as expert witness for the plaintiff, exertional heatstroke death of a professional baseball player, 2004 – 2005 (Attorney Barry Cepelewicz)
- Provided deposition June, 2006 as expert witness for the plaintiff, exertional heatstroke death of a college football player, Florida, 2004 – present (Attorney Virginia Buchanan)

- Provided deposition June 2007 as expert witness for the plaintiff, exertional heatstroke death of a teenage roller hockey player, 2007 – present (Attorney Donna Mich ilson)

I am consulting with your firm at the rate of $200.00 per hour, plus expe ıses. Travel time, if required, is calculated portal-to-portal with an 8-hour maximum per day.

Respectfully submitted,

Lawrence E. Armstrong

Lawrence E. Armstrong, Ph.D., FACSM
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Appendix A

University of Connecticut

Final Project Report
January 10, 2008

Thermoregulatory and Physiological Strain due to Athletic Equipment

Sponsor
Mrs. Kelci Stringer
via
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and the legal firm of
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Research Sponsor

The following proposed investigation results from telephone discussions with Attorney Paul M. DeMarco during April and May, 2007. The experimental design described below provides data that determine differences in heat and physiological strain, imposed by three uniform types, on humans who exercise in a hot environment. The following experimental design involves controlled, randomized experiments that were conducted at the University of Connecticut, Human Performance Laboratory (HPL).

Background

The effects of wearing a uniform (i.e., football, marching band, military) can be significant. For example, in American football the helmet, protective pads, jersey and pants reduce heat dissipation to the air. Exercise-induced metabolic heat production raises core body temperature without a plateau and readily induces "uncompensable" heat stress (i.e., the body's thermoregulatory systems cannot compensate adequately). To our knowledge, only one previously published (but not peer-reviewed) study quantified the thermal and cardiovascular strain due to wearing a football uniform.

References. (1) Kulka TJ, Kenney WL. Heat balance limits in football uniforms. The Physician and Sports Medicine 30:29-39, 2002. (2) Armstrong LE, Casa DJ, Millard-Stafford M, Moran DS, Pyne SW, Roberts WO. Exertional heat illness during training and competition. American College of Sports Medicine Position Stand. Medicine & Science in Sports & Exercise 39(3): 556-572, 2007.

Purpose of this Research

The purpose of this study is to describe differences of thermal and physiological responses during exercise in a hot environment, while wearing one of three uniforms per experiment:

Control - shorts, socks, sneakers (n = 10);

Partial - (shorts, socks, sneakers, jersey, pants, gloves, pads on legs, hips, arms, shoulders and chest) minus the helmet and shoulder pads (n = 10).

Full Uniform - (shorts, socks, sneakers, jersey, pants, gloves, pads on legs, hips, arms and chest) including Riddell shoulder pads and a Riddell helmet; the vintage of the helmet and shoulder pads was about 2001 (n = 10); or

Sneakers were substituted for football cleats. Subjects were tested during a pre-defined exercise protocol that simulates a workout. All experiments were conducted in a controlled hot environment (91.4°F, 33°C) during the months of September to November, 2007. Laboratory experiments focused on the differences in physiological responses that are induced by wearing these uniforms.

Because only one previous research study has evaluated human stress due to wearing a football uniform, this investigation will benefit thousands of football players (and other athletes who wear uniforms), at levels ranging from youth to professional leagues. This research and the resulting publications will be internationally important and visible.

Source: Armstrong LE, Casa DJ, Millard-Stafford M, Moran DS, Pyne SW, Roberts WO. Exertional heat illness during training and competition. American College of Sports Medicine Position Stand. Medicine & Science in Sports & Exercise 39(3): 556-572, 2007.

Scope of Work

This project included the following:

- time and expertise of three Ph.D. research physiologists and medical monitoring by one M.D. sports medicine physician
- preparation of a complete budget for approval by the University of Connecticut Research Foundation and the administrators of our college
- writing and submitting a complete research proposal to the University of Connecticut IRB and securing permission to conduct human experiments
- annual and ongoing reports to the IRB regarding these human experiments
- the efforts of up to 8 graduate students (partially funded for summer, 2007 within this proposal; all also received funding from departmental and other grant sources)

- ordering supplies and chemicals
- use of the HPL facilities and environmental chamber
- identifying appropriate, capable and healthy test subjects that have body characteristics similar to collegiate and NFL football line men
- meeting with test subjects to brief them regarding risks, benefits and rights
- conducting 30 experiments in the environmental chamber of the HPL plus 10 familiarization visits
- blood sampling by a trained phlebotomist and handling of blood samples with universal precautions
- ensuring medical monitoring of test subject safety (heart rate, core body temperature, clinical signs and symptoms) by a sports medicine/board certified physician, certified Athletic Trainers, and CPR-AED certified technicians
- calibrating, maintaining, and using analytical instruments
- statistical analyses
- preparation of the final report for submission to Paul M. DeMarco.

Attorney Paul M. DeMarco provided NFL uniforms for test subjects, in appropriate sizes, as prescribed by the experimental protocol.

Approval Process at the University of Connecticut

The final proposal, experimental design, and budget were approved by the University of Connecticut, Department of Kinesiology Chair, the Dean of the Neag School of Education, and the Research Foundation's Office for Sponsored Programs. The risks, benefits, and experimental protocol of this investigation were approved by the University of Connecticut, Institutional Review Board for Human Studies.

Methods

Ten healthy males (aged 19 – 34 years old) were selected on the basis of their previous and present athletic experiences (i.e., high school or college football experience but not highly-trained or heat acclimatized), body dimensions, and medical history (i.e., no chronic or exclusionary diseases). Each subject performed three laboratory trials of approximately 80 minute duration. This exercise involved repetitive box lifting and walking on a treadmill, with one 10-minute rest period between the lifting and walking exercise.

A subject was excluded from participation if he exhibited any of the following: (a) history of exertional heatstroke or recurring exercise-associated muscle cramps; (b) had a musculo-skeletal injury; (c) history of exercise-heat intolerance or lower back injury; (d) history of a disease or illness that contraindicated exercise in the heat; (e) faints when in the presence of needles or blood; or (f) was outside the age range of 19 - 34 yr; (g) weighed less than 230 pounds.

A controlled, randomized research design was employed. The experiments differed only in the uniform type worn.

Subjects were paid $25 for one preliminary visit to the HPL plus $75 per experiment. If they completed all visits successfully, they were given a completion bonus of $85.

At least 4 days prior to the first exercise session, subjects visited the laboratory once to practice selected elements of the exercise protocol. This preliminary visit required about 1 hour. During the initial visit, subjects had the following measurements taken: height, weight, age, and skin fold thickness at three sites (for calculation of body fat per cent). Whole body and regional body composition was assessed using a whole body densitometer (DEXA; Prodigy®, Lunar Corporation, Madison, WI).

Test subjects revealed all use of nutritional supplements, alcohol, drugs, medications, and stimulants during the 30 days prior to testing and during testing. Subjects performed only light exercise during the 24 hours prior to each experiment.

Subjects consumed the same diet during the 24 hours prior to each experiment, to reduce the effects of different nutrient status on exercise performance. A 24-hour food and fluid diary was kept prior to the first experimental test session, and this diet (including fluids) was replicated for the 24-hour period prior to subsequent trials.

On the morning of each experiment before they arrived at the Human Performance Laboratory (HPL), subjects did not eat until they consumed a controlled meal (1 bagel, cream cheese, water, 2 bananas). Subjects were allowed to relax and stretch for 1 hour after eating, to allow food to digest.

At the beginning of each experimental test session, body weight was measured on an electronic scale, and subjects inserted a rectal temperature probe 10 cm past the anal sphincter. A small urine sample was collected to assess hydration state via urine specific gravity. Subjects were not tested if they were dehydrated (urine specific gravity > 1.028) or had a fever (first rectal temperature reading > 37.8°C [>100°F]). Rectal temperature and heart rate were monitored every 4 min during exercise, to ensure test subject safety.
Subjects consumed no fluid during laboratory experiments.

The exercise-rest protocol consisted of 10 minutes of repetitive box lifting (RBL), 10 minutes of seated rest, followed by up to 60 minutes of treadmill walking. RBL consisted of lifting a 20.4 kg (45 lb) metal box with handles for 10 minutes. After lifting the box, subjects walked 2.4 m to place it on a platform that is 1.32 m high. An investigator slid the box down a ramp to the starting position after each lift. Each subject used his legs when lifting the box from the floor, as demonstrated and practiced during the familiarization visit. He placed his feet close to the box, bent his knees, and held up his head. Each subject received a minute-by-minute countdown and feedback regarding pace; the rate of box lifting was identical in all experiments. Based on a study conducted in our laboratory during Winter 2006, subjects lifted the box 100 times per 10 minute period; this was a challenging but achievable effort for average male college students and for these test subjects who all were former football players. After each 5-minute point, and while they were returning to get the next box, they looked at the heart rate monitor wrist watch and called-out heart rate. Also at 5-minute intervals, an investigator read rectal temperature. When 10 min of lifting ended, subjects sat and rested for 10 min. At the end of the 10-min rest period, subjects walked briskly on a treadmill (3.5 mph; 5.6 km/h; about 17:00/mile pace; 5%

grade), until 60 minutes or a termination criteria was reached. Exercise was terminated if: (a) signs and symptoms of heat illness (nausea, mental disorientation, lack of coordination, or dizziness) appeared; or (b) subjects elected to stop volitionally because of exhaustion; or (c) rectal temperature rose to 40°C (104°F) or higher. If none of these conditions existed, subjects completed 10 minutes of box lifting plus 60 minutes of treadmill walking. The pacing of the RBL exercise (boxes lifted per 10 minutes) and the treadmill exercise (3.5 mph) were controlled from day-to-day.

A 7-ml blood sample was drawn prior to exercise (all experiments) from an antecubital vein by a trained, experienced phlebotomist, using sterile technique. This was followed by the exercise protocol. Another 7-ml blood sample was drawn when exercise stopped (all experiments). Blood samples were collected via needle and vacutainer; catheters or cannulas were not utilized due to the possibility of snagging the catheter line on clothing or gear. No blood was collected on the familiarization day.

Perceptual responses (rating of perceived exertion, thermal sensation, thirst, pain intensity) were measured during convenient points in the protocol; these perceptual scales appear below in Appendix A. The rating of perceived exertion was applied to a central (overall) sensation, and local sensations at the arms and legs.

Outcome Variables

The key outcome variables were:
-- Borg's Rating of Perceived Exertion Scale
-- Thermal Sensation Scale
-- Thirst Sensation Scale
-- Pain Intensity Scale
-- rectal temperature (0.1°C) via thermister, measured every 5 minutes
-- skin temperature (0.1°C) via infrared sensing thermometer, measured every 5 minutes, at the forehead and neck
-- relative humidity of air inside the uniform near the lower back (via hand-held thermohygrometer)
-- heart rate (beats/min) via Polar heart rate monitor, measured every 5 minutes
-- blood pressure (mm Hg) via sphygmomanometer, measure pre- and post-exercise
-- total exercise time (0.1 minute)
-- glucose and lactate via venipuncture (immediately before and immediately post-exercise)
-- hematocrit and hemoglobin, allowing calculation of plasma volume movements into and out of the circulation (immediately before and immediately post-exercise)
-- osmolality of plasma (immediately before and immediately post-exercise)
-- environmental dry bulb temperature and relative humidity.

Data Analysis: Treatment effects were evaluated using a randomized, cross-over design. The sponsor desires to know the physiological/psychological strain induced by each uniform, and if significant differences are detected between uniforms. Analysis of Variance (ANOVA) (uniform X time) was used to evaluate variables with more than two sampling points. In the event of significant F values ($P<.05$), *post hoc* analysis was done via the Neuman-Keuls test. Student's t-test was used to evaluate differences between the means of variables that are measured only

pre- and post-exercise. Prediction of rectal temperature and heart rate, for a hypothetical 2-hour mark, was accomplished via regression analysis. All values are reported as mean ± standard deviation (SD).

Abbreviations

The three experimental trials are named via the following terms:

Control - shorts, socks, sneakers;

Partial - (shorts, socks, sneakers, jersey, pants, gloves, pads on legs, hips, arms, shoulders and chest) minus the helmet and shoulder pads.

Full Uniform - (shorts, socks, sneakers, jersey, pants, gloves, pads on legs, hips, arms and chest) including Riddell shoulder pads and a Riddell helmet; the vintage of the helmet and shoulder pads was about 2001; or

All subjects (n = 10) completed the Control, Partial, and Full Uniform experiments. The abbreviation **RBL** refers to the process of repetitive box lifting.

Results

Environmental Conditions

Table 1. The air temperature inside the Human Performance Laboratory environmental chamber was virtually identical for all experiments.

Experiment	Number of Measurements	Mean Air Temperature (°C)	Standard Deviation
Control	30	33.0	0.7
Partial (no H or SP)	30	33.1	0.8
Full Uniform	29	33.0	0.7

Table 2. The air relative humidity (%rh) inside the Human Performance Laboratory environmental chamber was virtually identical for all experiments.

Experiment	Number of Measurements	Mean Relative Humidity (°C)	Standard Deviation
Control	30	48.7	5.5
Partial (no H or SP)	30	49.4	5.3
Full Uniform	29	48.0	5.9

The air movement for the uniform study differed slightly by location. Near the box lifting station, the average air speed was 25 feet/min = 0.417 feet/sec = 0.13 m/sec = 0.3 mph. On the treadmill (1 m above the treadmill belt) the air speed was 10 feet/min = 0.167 feet/sec = 0.05 m/sec = 0.1 mph.

Subject Characteristics

Table 3. The ten male test subjects had played football for at least three years and had the following personal characteristics.

Subject	Age (y)	Body weight (kg / lb)	Height (cm / in)	Body fat (%) [a]	Fat Mass (kg / lb) [a]	Lean Body Mass (kg / lb) [a]
1	33.7	116.94 (257.81)	199.6 (78.6)	27.6	30.5 (67.2)	80.2 (176.8)
3	27.1	113.62 (250.48)	184.9 (72.8)	26.8	29.1 (64.2)	79.6 (175.5)
4	26.3	110.36 (243.30)	189.2 (74.5)	23.3	24.8 (54.7)	81.6 (179.9)
7	19.3	105.37 (232.30)	183.4 (72.2)	26.2	26.6 (58.6)	75.1 (165.6)
8	20.8	107.95 (237.99)	181.6 (71.5)	26.7	28.1 (61.9)	77.0 (169.8)
9	23.5	121.02 (266.80)	176.5 (69.5)	34.7	41.0 (90.4)	77.0 (169.8)
10	21.7	117.93 (259.99)	179.1 (70.5)	37.7	43.0 (94.8)	70.9 (156.3)
11	21.6	131.09 (289.00)	183.6 (72.2)	40.1	50.6 (111.5)	75.6 (166.7)
12	19.1	110.13 (242.80)	173.5 (68.3)	30.1	32.3 (71.2)	75.2 (165.8)
13	19.9	106.64 (235.10)	185.9 (73.2)	28.0	29.0 (63.9)	74.5 (164.2)
Mean	23.8	117.41 (258.84)	183.9 (72.4)	30.1	33.5 (73.9)	76.7 (169.1)
± SD	4.3	12.59 (27.75)	6.3 (2.5)	5.5	8.4 (18.5)	3.2 (7.1)

[a], as determined by DEXA (dual x-ray absorptiometry) scan, considered to be today's gold standard body composition technique

Hydration Status at the Beginning of Daily Testing

The hydration state of test subjects was assessed by measuring morning body weight and urine specific gravity. These two variables are considered to be among the most useful markers of dehydration, normal hydration, or over-hydration (Armstrong, L.E. Assessing hydration status: The elusive gold standard. *Journal of the American College of Nutrition* 26(5):575S-584S, 2007). Each subject consumed a prescribed amount of fluid before each experiment, to ensure that he was not dehydrated. This involved drinking 20 ounces (591 ml) of water after dinner (night before testing) and 20 ounces (591 ml) of water immediately upon waking (on the morning of testing).

Body weight, measured only while wearing under pants, and urine specific gravity were statistically similar on all days. The mean (i.e., average) and standard deviation values below indicate that subjects entered morning tests in a similar state of hydration.

Table 4. Mean (± SD) body weight and urine specific gravity at the point of arrival at the laboratory for three experiments.

Experiment	Number of Subjects	Mean ± SD Body Weight (kg)	Mean ± SD Urine Specific Gravity (unitless)
Control	10	114.87 ± 8.48	1.015 ± 0.008
Partial (no H or SP)	10	114.78 ± 8.54	1.018 ± 0.007
Full Uniform	10	115.65 ± 8.47	1.016 ± 0.007

Exercise Findings

The different uniforms induced varied amounts of thermal/cardiovascular/physiological strain. This resulted in different numbers of subjects completing the entire 80-min period in the environmental chamber (i.e., 10 min repetitive box lifting, 10 min rest, 60 min treadmill walking), and a different number of subjects continuing exercise at each 5-minute milestone (see Table 5).

Because no subject was stopped by investigators (i.e., due to rectal temperature or heart rate exceeding the pre-established safety limits), exhaustion was the reason that all subjects stopped treadmill exercise. Only two experiments were terminated due to an investigator deciding to stop exercise, on the basis of signs and symptoms of impending heat illness or obvious exhaustion (i.e., truncal ataxia, inability to walk without holding the handrail, inability to maintain the treadmill walking pace).

Table 5. The number of subjects completing exercise during each 5-min segment of testing.

Experiment	Treadmill Walking Time (min)													
	RBL	Rest	5	10	15	20	25	30	35	40	45	50	55	60
Control	10	10	10	10	10	10	10	10	8	7	7	7	7	7
Partial (no H or SP)	10	10	10	10	10	10	8	7	6	6	6	5	3	3
Full Uniform	10	10	10	10	10	9	8	7	5	4	3	1	1	1

Skin Measurements

Skin temperature was measured via infrared sensor, on the back of the neck and the forearm in all experiments. Table 6 provides these data. A main effect of uniform type existed when all uniforms were combined. At the forearm: the skin temperature for Full Uniform was greater than Control ($P<.05$). At the back of the neck: Full Uniform was greater than Control ($P<.001$), and Full Uniform was greater than Partial ($P<.05$).

Table 6. Mean (± SD) skin temperature (°C) measured at two sites (n = 8 to 10).

Experiment	Measurement Site	Pre-RBL	Immediately Post-RBL	Start of Treadmill	Final Treadmill
Control	Back of neck	33.0 ± 1.0	33.7 ± 1.0	34.1 ± 0.5	34.5 ± 1.2
	Forearm	33.0 ± 1.0	32.8 ± 0.8	33.4 ± 0.9	34.5 ± 1.0
Partial (no H or SP)	Back of neck	33.5 ± 0.9	33.7 ± 0.8	34.1 ± 0.7	35.3 ± 1.0
	Forearm	33.6 ± 0.8	33.7 ± 0.8	34.3 ± 0.7	35.0 ± 0.6
Full Uniform	Back of neck	33.4 ± 1.4	34.2 ± 1.1	35.1 ± 0.6	35.6 ± 1.0
	Forearm	33.4 ± 0.9	33.7 ± 1.0	35.1 ± 0.5	35.2 ± 0.6

Note: statistical differences are described in the text above

The relative humidity of the air inside the uniform, near the lower back, was measured with a hand-held thermohygrometer. Table 7 provides these data.

Table 7. Relative humidity (%) measured inside the uniform, under the jersey in the region of the lower back (all uniform types, n = 10).

Experiment	Initial	½ RBL	Post-RBL	T-mill Min 0	T-mill Min 20	T-mill Min 40	T-mill Final
Control [a]	47 ± 4 [b]	47 ± 4 [b]	47 ± 4 [b]	47 ± 4 [b]	47 ± 4 [b]	47 ± 4 [b]	47 ± 4 [b]
Partial (no H or SP)	75 ± 9	74 ± 8	80 ± 8	81 ± 11	84 ± 8	87 ± 6	89 ± 4
Full Uniform	69 ± 11	66 ± 11	78 ± 9	81 ± 8	86 ± 9	87 ± 6	90 ± 5

[a], no uniform was worn; this value represents the ambient relative humidity measured for the air

[b], Control was significantly different from all other uniform types, at all time points (P<.000001)

Sweat Production

Sweat rate, expressed as liters per hour, appears below for three uniform types. Other sweat rate data appear in Table 19.

Table 8. Mean (±SD) rate of sweat production (different exercise durations).

Experiment	Mean (± SD) sweat rate (liters/h)	Number of subjects
Control	1.24 ± 0.16	8
Partial (no H or SP)	1.86 ± 0.25 [a]	8
Full Uniform	2.05 ± 0.34 [a]	8

[a], significantly greater than the Control clothing (P<.001 to .0001)

Rectal Temperature

Figure 1 depicts the rectal temperatures that were recorded during each experimental trial (Full Uniform, Partial Uniform (no helmet or shoulder pads), and Control (shorts, socks, sneakers only). Clearly, as the time of exercise increased, the differences in rectal temperature (due to uniform type) show that different amounts of heat were stored in body tissues and organs. The final rectal temperatures (i.e., rightmost data points in Fig. 1) were lower for Control versus Partial (P<.025), and lower for Control versus Full Uniform (P<.05). This means that exhaustion occurred sooner in Full Uniform and Partial (versus Control), in part due to higher rectal temperatures.

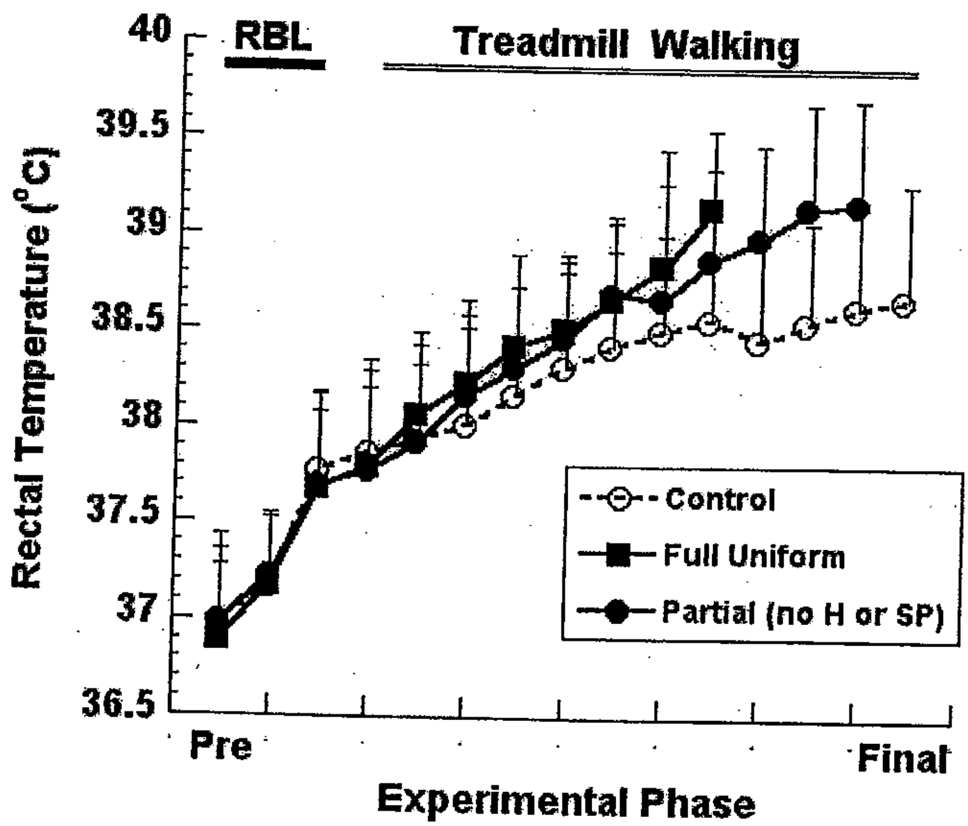

Figure 1. Rectal temperature during RBL, rest, and treadmill walking while wearing three different uniform types. Data points depict only segments with five or more subjects.

The number of test subjects who reached a rectal temperature of 39.0°C (102.2°F) was recorded as follows: Control – 4, Partial – 6, Full Uniform – 6. This level of hyperthermia is considered to be the lower body temperature threshold at which exertional heatstroke begins.

The change of rectal temperature is of interest because it allows calculations on the basis of any exercise duration. Table 9 presents the mean rectal temperature change from Pre-exercise to the end of treadmill walking (different durations). This included 10 minutes of RBL, 10 minutes of rest, and up to 60 minutes of treadmill walking; it is important to note that the duration of exercise (to the point of exhaustion) in Table 9 was unique for each uniform type and for each subject.

Table 9. The mean rectal temperature increase (°C) from the beginning of box lifting exercise (Pre-RBL) to the end of treadmill walking (different durations).

Experiment	Mean (± SD) rectal temperature increase (°C) from Pre-RBL to end of treadmill walking for each subject	Number of subjects exercising, at four time points of treadmill walking			
		at 15 min	at 30 min	at 45 min	at 60 min
Control	1.81 ± 0.40	10	10	7	7
Partial (no H or SP)	2.36 ± 0.24 [a]	10	7	6	3
Full Uniform	2.37 ± 0.45 [a]	10	7	3	1

[a], significantly different from Control (P<.0005)

Note 1: the value for rectal temperature change in column 2 includes 10-min of RBL, 10 min of rest, and treadmill walking (different durations).

Regarding rectal temperature, one segment of the exercise protocol was selected for further analysis—specifically, the segment from 20 minutes to 40 minutes of treadmill walking. This segment was selected because it represented the time point at which rectal temperature and heart rate began to separate (Figures 1 and 2), due to uniform type. The rate of rectal temperature rise was markedly different in the three experimental conditions evaluated here (Table 10). Partial Uniform (no helmet or shoulder pads) resulted in a doubling of rectal temperature rise, versus the Control clothing (i.e., shorts, socks, sneakers), whereas the Full Uniform caused rectal temperature to rise 2.7 times faster than Control. Comparisons of the Partial Uniform and the Full Uniform to Control indicated that (from minute 20 to minute 40) the helmet and shoulder pads accounted for 43% of the total rise of rectal temperature (i.e., 0.20 / 0.47 = 0.43*100 = 43%) of the Full Uniform.

Table 10. The mean rectal temperature increase (°C) from minute 20 to minute 40 of treadmill walking.

Experiment	Mean Rectal Temperature Change from Min 20 to Min 40 (°C)	Standard Deviation	No. of subjects
Control	0.27	± 0.15	7 - 10
Partial (no H or SP)	0.54 [a]	± 0.17	6 - 10
Full Uniform	0.74 [b]	± 0.05	4 - 9

[a], significantly different from Control (P<.0005)
[b], significantly greater than Partial and Control (P<.001 to .05)

The change of rectal temperature also was expressed per unit of **exercise time** (on the treadmill; see Table 11) and **total exposure time** (i.e., 10 minutes of RBL + 10 minutes of rest + up to 60 minutes of treadmill walking; see Table 12). The rate of rectal temperature rise, and the differences between uniforms, were greater during exercise (Table 11) than during the total heat exposure (which included a 10-min rest, seeTable 12). During the entire treadmill exercise bout, Partial Uniform (no helmet or shoulder pads) caused rectal temperature to rise 1.4 times faster than Control, whereas the Full Uniform caused rectal temperature to rise 1.9 times faster than Control. During the entire treadmill exercise bout, the helmet and shoulder pads accounted for 56% of the total rectal temperature rise (i.e., 0.019 / 0.034 = 0.56*100 = 56%) of the Full Uniform.

Table 11. The mean rectal temperature increase (°C), expressed per minute of treadmill exercise (no rest, no RBL).

Experiment	Mean (± SD) rectal temperature change (°C/min) per min of treadmill walking	Mean (± SD) total duration of treadmill exercise to the point of exhaustion (min)	Number of Subjects
Control	0.037 ± 0.015	51.7 ± 13.4	10
Partial (no H or SP)	0.052 ± 0.012	43.1 ± 15.6	10
Full Uniform	0.071 ± 0.032 [a]	36.2 ± 13.2	10

[a], significantly greater than Control and Partial (P<.0005)

Table 12. The mean rectal temperature increase (°C), expressed per minute of total exposure time (exercise + rest) in the environmental chamber. This table represents the beginning of RBL to the end of treadmill walking (different durations).

Experiment	Mean (± SD) rectal temperature change (°C/min) during the 80 min heat exposure	Average total exposure time (min)	Number of Subjects
Control	0.026 ± 0.008	71.7	10
Partial (no H or SP)	0.034 ± 0.006 [a]	63.1	10
Full Uniform	0.042 ± 0.010 [a, b]	56.2	10

[a], significantly greater than Control ($P<.05$ to .0005)
[b], significantly greater than Partial ($P<.05$)
Note 1: the value for rectal temperature change in column 2 includes 10-min of RBL + 10 min of rest + treadmill walking (different durations).

Heart Rate

Heart rate presents an indication of physiological strain on the circulatory system during exercise. Figure 2 below presents mean (± SD) heart rate during RBL, rest, and treadmill walking while wearing three different uniform types. Data points depict only segments with five or more subjects. In part due to large standard deviations at all data points (i.e., the differences between subjects were large), heart rate was not significantly different at most points of measurement.

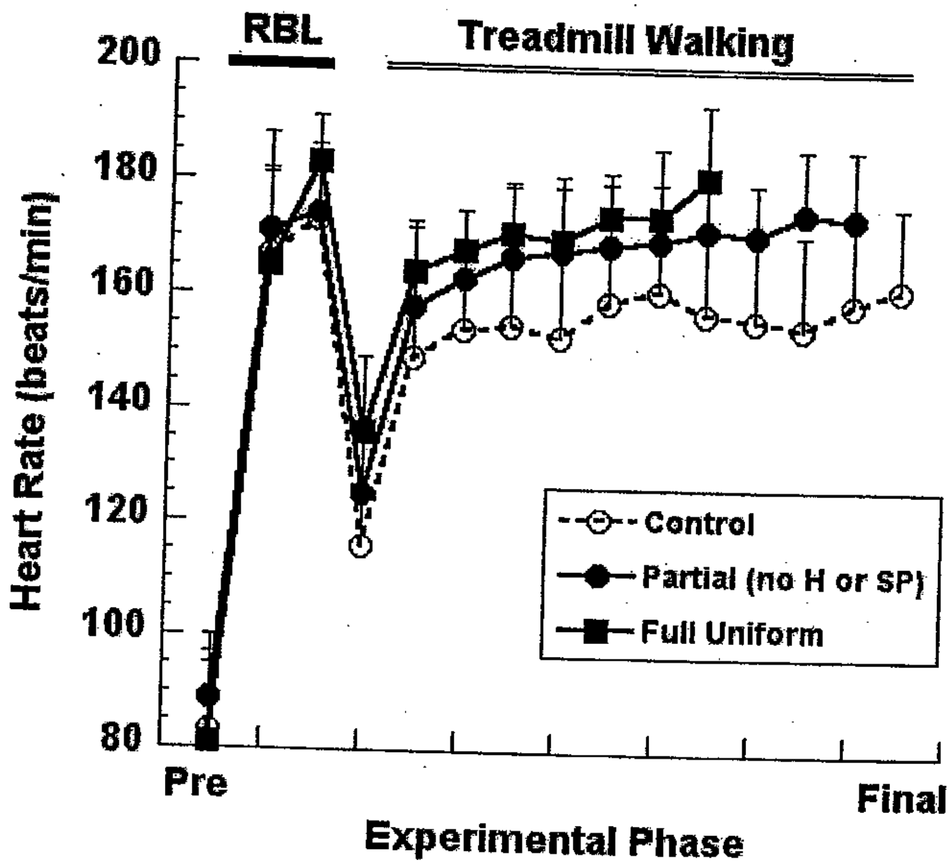

Figure 2. Mean (± SD) heart rate during RBL, rest and treadmill walking, while wearing three different uniform types. Data points depict only segments with five or more subjects.

At 40 minutes of treadmill exercise, differences were detected between Control and Partial, and between Control and Full Uniform (Table 13). Similarly, at the end of treadmill exercise (for the uniforms shown in Figure 2), differences were detected (Table 14) between Control and Partial (P<.025), and between Control and Full Uniform (P<.01). It is important to note that the different uniform types resulted in different exercise durations.

Table 13. Mean (± SD) heart rate at the 40th minute of treadmill exercise.

Experiment	Mean ± SD Heart Rate (beats/min)	Number of Subjects
Control	156 ± 14	7
Partial (no H or SP)	171 ± 9 [a]	6
Full Uniform	181 ± 9 [a]	4

[a], significantly greater than Control (P<.01)

Table 14. Mean (± SD) heart rate at the end of treadmill exercise (different durations).

Experiment	Mean (± SD) Heart Rate (beats/min)	Number of Subjects
Control	164 ± 14	10
Partial (no H or SP)	178 ± 8 [a]	10
Full Uniform	180 ± 13 [a]	10

[a], significantly greater than Control (P<.025)

Blood Pressure

Blood pressure, measured with a sphygmomanometer and stethoscope, is the force exerted by circulating blood on the walls of blood vessels. This term generally refers to arterial pressure. Although many modern devices no longer use mercury, vascular pressures are universally reported in millimeters of mercury (mmHg).

The **systolic** arterial pressure is defined as the peak pressure in the arteries, which occurs near the beginning of the cardiac cycle; the **diastolic** arterial pressure is the lowest pressure (at the resting phase) of the cardiac cycle. The term hypotension refers to an abnormally low blood pressure. This is important because hypotension may result in weakness, fainting, or cessation of exercise in the heat.

Statistical analyses identified a main effect of time on systolic blood pressure (i.e., it decreased across time) when all uniforms were combined (Pre-RBL was greater than Final, P<.0001; Post-RBL was greater than Final, P<.0001). Similarly, a main effect of time on diastolic blood pressure was observed (i.e., it decreased across time) when all uniforms were combined (Pre-RBL was greater than Post-RBL, P<.005; Pre-RBL was greater than final, P<.0005).

Thus, exercise in the heat resulted in a reduced blood pressure (i.e., relative hypotension). It is possible that this change of blood pressure affected the duration of treadmill exercise by inducing a sense of fatigue or exhaustion.

Table 15. Mean (± SD) systolic blood pressure (mmHg) at three time points.

Experiment	Number of Subjects	Experimental Protocol Phase		
		Pre-RBL	Post-RBL	Final T-mill Walking
Control	9	119 ± 6	131 ± 10	110 ± 6
Partial (no H or SP)	9	120 ± 8	119 ± 12 [a]	106 ± 12
Full Uniform	9	118 ± 11	119 ± 13 [a]	116 ± 12

[a], significantly different from Control (P<.05)
Note 1: a main effect of time was detected when all uniforms were combined (Pre-RBL versus Final, P<.0001; Post-RBL versus final, P<.0001)

Table 16. Mean (± SD) diastolic blood pressure (mmHg) at three time points.

Experiment	Number of Subjects	Experimental Protocol Phase		
		Pre-RBL	Post-RBL	End of T-mill Walking
Control	9	75 ± 9	74 ± 8	72 ± 6
Partial (no H or SP)	9	80 ± 9	62 ± 12	62 ± 12
Full Uniform	9	79 ± 7	69 ± 14	65 ± 9

Note 1: all uniform types were statistically similar
Note 2: a main effect of time was detected when all uniforms were combined (Pre-RBL versus Post-RBL, P<.005; Pre-RBL versus final, P<.0005)

Exercise Time

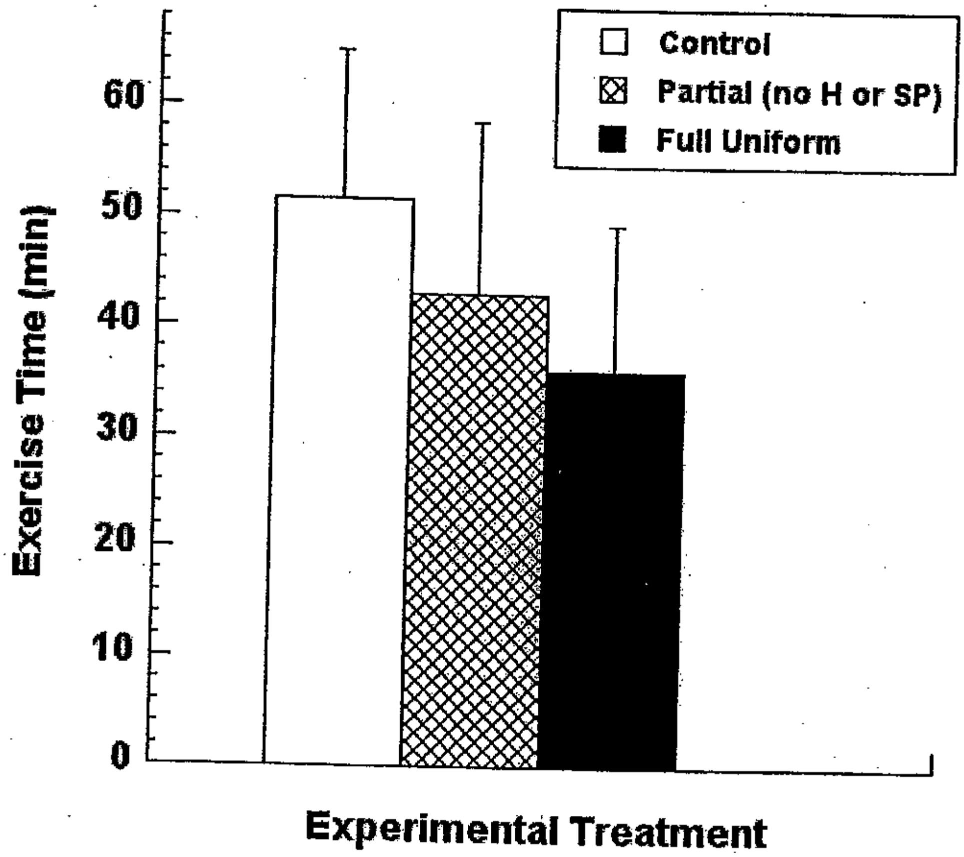

Figure 3. Elapsed treadmill exercise time (min) while wearing three uniform types (n = 10). The exercise time of Full Uniform was significantly less than Control (P<.05). The exercise time of Partial was significantly less than Control (P<.005) and significantly greater than Full Uniform (P<.005). Treadmill exercise began after 10 min of RBL and 10 min of rest.

Blood Analyses

Blood samples were drawn before RBL began and when treadmill exercise ended. Blood lactic acid concentration (Hla), a product of anaerobic metabolism, is an index of the intensity of exercise. Blood glucose concentration (Glu) expresses the availability of this essential fuel. Plasma osmolality (P_{osm}) and percent change of plasma volume (% change PV) indicate the concentration of blood and the loss of blood plasma from the circulation, respectively.

Table 17. Blood constituents measured before and after exercise (n = 10 for all uniforms). No between-uniform differences existed for any blood variable below.

Experiment	Pre Hla	Post Hla	Pre Glu	Post Glu	Change P_{osm}	% Change PV
Control	1.3 ± 0.6	1.3 ± 0.5	6.2 ± 5.5	5.5 ± 0.7	9.2 ± 6.9	- 7.2 ± 5.4
Partial (no H or SP)	1.6 ± 0.6	1.5 ± 0.4	6.2 ± 5.8	5.8 ± 0.7	3.8 ± 4.9	- 3.1 ± 5.8
Full Uniform	1.4 ± 0.7	1.7 ± 0.5	5.6 ± 5.8	5.8 ± 0.8	5.1 ± 5.8	- 3.9 ± 3.3

Perceptual Ratings

Perceptual rating scales allowed quantitative measurements to be made of perceived exertion during exercise, as well as thermal, thirst and pain sensations (Table 18). These ratings involved the following instruments: Borg's Rating of Perceived Exertion Scale, Thermal Sensation Scale, Thirst Sensation Scale, and Pain Intensity Scale. A main effect of time (P<.001 to .05) existed for all ratings, in that these values increased from Pre-RBL to Final. However, no perceptual rating difference was detected between uniform types.

Table 18. Mean (±SD) perceptual ratings measured at five time points (n = 8 to 10). The perceptual instruments are described in the text above.

Uniform Type	Time Point [a]	Perceived Exertion [b]	Thermal	Thirst	Pain Intensity
Control	Pre-RBL	6 ± 1	4.5 ± 0.5	2 ± 1	0 ± 1
	End RBL	14 ± 3	6.0 ± 1.0	5 ± 2	2 ± 2
	Start Treadmill	8 ± 2	5.5 ± 1.0	3 ± 1	1 ± 1
	Min 20	12 ± 3	6.0 ± 1.0	5 ± 2	2 ± 2
	Final	14 ± 3	6.0 ± 2.0	7 ± 2	3 ± 3
Partial (no H or SP)	Pre-RBL	6 ± 1	5.0 ± 0.5	2 ± 1	0 ± 1
	End RBL	16 ± 2	6.0 ± 1.0	5 ± 2	3 ± 2
	Start Treadmill	8 ± 2	5.0 ± 1.0	4 ± 1	1 ± 1
	Min 20	15 ± 3	6.5 ± 1.0	6 ± 2	3 ± 3
	Final	18 ± 2	7.0 ± 1.0	8 ± 1	4 ± 3
Full Uniform	Pre-RBL	6 ± 1	4.5 ± 1.0	2 ± 1	0 ± 1
	End RBL	16 ± 2	6.0 ± 0.5	5 ± 1	2 ± 1
	Start Treadmill	9 ± 3	5.5 ± 0.5	4 ± 2	1 ± 1
	Min 20	14 ± 3	7.0 ± 0.5	6 ± 1	2 ± 2
	Final	18 ± 1	7.5 ± 0.5	7 ± 1	4 ± 3

[a], Pre-RBL, immediately before repetitive box lifting (RBL) task began; End RBL, immediately after the repetitive box lifting (RBL) task ended; Start treadmill, immediately after a 10-min rest period and treadmill walking began; Min 20, measured during the 20th minute of treadmill walking; Final, measured immediately before treadmill walking ended.

Effects of Body Composition on Physiological Responses

Statistical correlation provides an index of the relation between two or more variables. A *perfect* correlation of +1.0 or -1.0 occurs only when the data points all lie exactly on a straight line. A correlation greater than 0.8 is described as *strong*; this indicates that the dependent entity is likely to react predictably to changes in the independent entity. A correlation coefficient between 0.5 and 0.8 is described as *moderate*. A correlation less than 0.5 is described as *weak*, suggesting that a relationship may not exist. A coefficient of zero implies no relationship between the two variables.

Correlation coefficients were calculated, to show the relationships between body composition measurements and key physiological responses. This analysis compared key test subject characteristics (i.e., age, body weight, % body fat, height, and lean body mass) to exercise time, rectal temperature, and heart rate measurements. Only the Full Uniform was analyzed in this way; this was not a comparison of uniforms. Table 20 presents the matrix of correlations coefficients, and their significance levels as derived from linear regression analyses.

Table 20. Matrix of the statistical correlations (r) that describe relationships between test subject characteristics and key physiological responses during the Full Uniform experiments only (n = 8 to 10).

	Exercise Time (min)	Final T_{re} (°C)	T_{re} Change (°C)	Final Heart Rate (beats/min)	Heart Rate Change (beats/min)
Age (years)	+ 0.41	+ 0.57 [a]	+ 0.53 [a]	- 0.10	- 0.19
Body Weight (kg)	- 0.19	- 0.27	- 0.08	- 0.40	- 0.23
Body Fat (%)	- 0.66 [a, c]	- 0.61 [a]	- 0.66 [a, c]	- 0.36	- 0.39
Lean Body Mass (kg)	+ 0.68 [a, c]	+ 0.65 [a, c]	+ 0.84 [b, d]	+ 0.22	+ 0.36
Height (cm)	+ 0.41	+ 0.33	+ 0.28	- 0.39	- 0.25

[a], moderate correlation
[b], strong correlation
[c], statistically significant (P<.05)
[d], statistically significant (P<.005)

Prediction of Rectal Temperature and Heart Rate at the Hypothetical 2-hour Time Point

The statistical regression analysis of the plot lines for Full Uniform, Partial, and Control allowed a prediction of the rectal temperature (Figure 1) and heart rate (Figure 2) values that would have been reached by test subjects, had they continued to exercise longer. The following values were calculated, via regression analysis, as though treadmill walking had continued to the 2-hour time point. The final six data points (25 min period) for each uniform type (Figures 1 and 2) were used.

- Rectal temperature after 2 hours of treadmill walking is predicted to be:
  - Full Uniform – 42.0°C (107.6°F)
  - Partial (no H or SP) – 40.8°C (105.4°F)
  - Control – 39.1°C (102.2°F)
- Heart rate after 2 hours of treadmill walking is predicted to be:
  - Full Uniform – 218 beats/min
  - Partial (no H or SP) – 190 beats/min
  - Control – 163 beats/min

Conclusions

The three experimental trials are named via the following terms:

Control – the no uniform condition in which subjects wore only shorts, socks and sneakers (n = 10 subjects)

Partial (no H or SP) – the Full Uniform minus helmet and shoulder pads (n = 10 subjects)

Full Uniform – shorts, white athletic socks, long socks, sneakers, gloves, jersey, pants, pads on legs, hips, arms (n = 10 subjects)

All subjects completed the Control, Partial, and Full Uniform experiments.

8. Air temperature, air relative humidity, and subject hydration state (i.e., body weight, urine specific gravity) were controlled from day-to-day.
9. Test subjects stopped because of exhaustion, not due to their reaching pre-established rectal temperature or heart rate safety limits.
10. Skin temperature was greater in Full Uniform versus Control (at the neck and forearm) and Full Uniform versus Partial (at the neck).
11. Humidity (%rh) was the same inside the three uniforms (Control, Partial, Full).
12. Sweat rates were similar in Partial and Full Uniform; both of these were greater than Control clothing.
13. The number of test subjects who reached a rectal temperature of 39.0°C (102.2°F) was recorded as follows: Control – 4, Partial – 6, Full Uniform – 6. This level of hyperthermia is considered to be the lower body temperature threshold at which exertional heatstroke begins.
14. From Min 20 to Min 40 of treadmill exercise, Partial (no helmet and no shoulder pads) caused an increase of rectal temperature (i.e., due to heat storage in the deep tissues of the body) that was 2.0 times greater than Control; Full Uniform caused an increase of rectal temperature that was 2.7 times greater than Control; the helmet and shoulder pads caused 43% of this increase in rectal temperature.
15. During the entire treadmill exercise bout, Partial Uniform (no helmet or shoulder pads) caused rectal temperature to rise 1.4 times faster than Control, whereas the Full Uniform caused rectal temperature to rise 1.9 times faster than Control. During the entire treadmill exercise bout, the helmet and shoulder pads accounted for 56% of the total rectal temperature rise of the Full Uniform.
16. Blood pressure dropped similarly in all uniform types during the entire protocol (RBL + rest + treadmill exercise).
17. Heart rate increased similarly in all uniform types during the entire protocol (RBL + rest + treadmill exercise).
18. Blood constituents were similar in all uniform types.
19. Perceived exertion, thirst, thermal and pain ratings were similar in all uniform types.
20. Exercise time (i.e., treadmill exercise time in the heat), rectal temperature, and change of rectal temperature were significantly correlated with body fat per cent and lean body mass.
    a. Test subjects with a higher body fat percent exhibited a shorter time to exhaustion, and thus a smaller increase of rectal temperature (versus those with a lower body fat per cent).

b. Test subjects with a higher lean body mass (i.e., muscle, lean tissue, bones; exclusive of body fat) exhibited a longer time to exhaustion, and thus had a larger increase of rectal temperature.

14. The statistical regression analysis of the lines for the Control, Partial and Full uniforms (see Figure 1 and Figure 2) allow a statistical projection of the physiological values that would have been reached, during a 2-hour exercise bout.

- Rectal temperature after 2 hours of treadmill walking is predicted to be:
  - Full Uniform – 42.0°C (107.6°F)
  - Partial (no H or SP) – 40.8°C (105.4°F)
  - Control – 39.1°C (102.2°F)
- Heart rate after 2 hours of treadmill walking is predicted to be:
  - Full Uniform – 218 beats/min
  - Partial (no H or SP) – 190 beats/min
  - Control – 163 beats/min

Appendices

The following pages contain forms and scales used during this investigation.

Appendix A – Perceptual Scales: rating of perceived exertion, thermal sensation, thirst, pain

Appendix A – Four Perception Scales

Thirst Scale (1-9 pt.)

1	Not Thirsty At All
2	
3	A Little Thirsty
4	
5	Moderately Thirsty
6	
7	Very Thirsty
8	
9	Very, Very Thirsty

Source: Engell, D. B., O. Maller, M. N. Sawka, R. N. Francesconi, L. Drolet, and A. J. Young. Thirst and fluid intake following graded hypohydration levels in humans. Physiol. Behav. 40:229-236, 1987.

Thermal Perception (1-8 pt.)

0.0	Unbearably Cold
0.5	
1.0	Very Cold
1.5	
2.0	Cold
2.5	
3.0	Cool
3.5	
4.0	Comfortable
4.5	
5.0	Warm
5.5	
6.0	Hot
6.5	
7.0	Very Hot
7.5	
8.0	Unbearably Hot

Source: Young AJ, Sawka MN, Epstein Y, Decristofano B, and Pandolf KB. Cooling different body surfaces during upper and lower body exercise. J Appl Physiol 63:1218-1223, 1987.

Rating of Perceived Exertion (6-20 pt.)

6	
7	Very, Very Light
8	
9	Very Light
10	
11	Fairly Light
12	
13	Somewhat Hard
14	
15	Hard
16	
17	Very Hard
18	
19	Very, Very Hard
20	

Source: Borg G. Perceived exertion as an indicator of somatic stress. *Scandinavian Journal of Rehabilitative Medicine* 2-3:92-98, 1970.

Pain Intensity Scale (0 – 10 pt.)

0	No pain at all
½	Very faint pain (just noticeable)
1	Weak pain
2	Mild pain
3	Moderate pain
4	Somewhat strong pain
5	Strong pain
6	
7	Very strong pain
8	
9	
10	Extremely intense pain (almost unbearable)
•	Unbearable pain

Source: Motl, R. W., J. O'Connor P, L. Tubandt, T. Puetz, and M. R. Ely. Effect of caffeine on leg muscle pain during cycling exercise among females. *Med Sci Sports Exerc.* 38:598-604, 2006.